

# AQUAGENICS INCORPORATED

WATER & WASTEWATER ENGINEERING SERVICES

April 24, 2017

Mr. Michael Jeffers  
Water & Sewer Managing Engineer  
Town of Exeter  
13 Newfields Road  
Exeter, NH 03833

**LETTER REPORT  
EVALUATION OF TREATMENT PROCESS ALTERNATIVES FOR  
THE CONTROL OF DISINFECTION BYPRODUCTS (DBPs)  
EXETER SURFACE WATER TREATMENT PLANT  
EXETER, NEW HAMPSHIRE**

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Dear Mr. Jeffers:

The following **Report** presents the findings, conclusions, and recommendations of our **Evaluation** of treatment process alternatives for the control of disinfection byproducts at the Exeter, New Hampshire Surface Water Treatment Plant to meet drinking water compliance regulations. It was prepared for the Town of Exeter to satisfy the New Hampshire Department of Environmental Services (NHDES) requirement for such an evaluation and report contained in **Docket No. 17-004 WD – Administrative Order by Consent Agreement** dated March 10, 2017.

**Background**

The Town of Exeter, New Hampshire previously completed an investigation into the production and control of total trihalomethanes (TTHMs) for its Surface Water Treatment Plant (SWTP). The objectives of this investigation were:

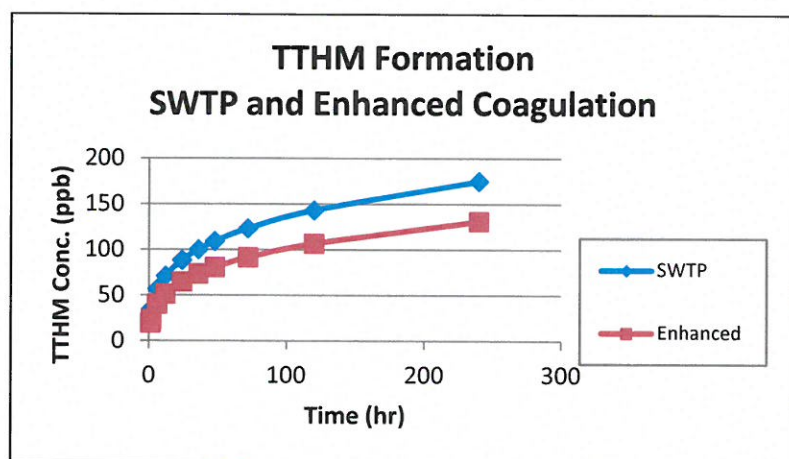
- to identify causes of elevated TTHM levels that have prevented the SWTP from complying with disinfection byproduct drinking water regulations and
- to identify options related to the existing treatment processes that may be instituted to reduce such levels for regulatory compliance

The investigation results were in the report entitled “TTHM Production and Control Investigation” that was submitted to the New Hampshire Department of Environmental Services (NHDES) and approved in December 2016.

The investigation concluded that several actions that could be undertaken at the SWTP to reduce the production of TTHMs include:

- Implement Enhanced Coagulation
- Optimize clearwell sodium hypochlorite addition to meet CT requirements
- Discontinue filter backwash recycling
- Optimize finished water pH associated with corrosion control

However, even with implementation of these actions, the overall reduction in TTHM concentration would be approximately 15 to 20 percent on the average, and would not be sufficient to consistently achieve compliance. The chart below shows projected TTHM concentrations as a function of time for implementing enhanced coagulation (Enhanced) and for the routine coagulation chemistry practiced at the SWTP (SWTP). The projections are based on a TTHM formation model that was developed by Amy et al. (*Developing Models for Predicting Trihalomethane Formation Potential Kinetics, Journal of the American Water Works Association, 1987*) and that was calibrated based on enhanced coagulation jar testing results conducted at the SWTP in June 2016. The projections are for a water temperature of 25 degrees Centigrade, pH of 7.5, and an applied chlorine dosage of 2.5 mg/L.



Subsequently, NHDES requested that the Town evaluate additional treatment process alternatives for TTHM reduction such as post-production aeration of the finished water and/or chloramination as a means of secondary disinfection and submit its findings, conclusions and recommendations by March 31, 2017. This submittal date was later changed to April 30, 2017. Additional alternatives that the Town has evaluated include: MIEX® anion resin pre-treatment, GAC (granular activated carbon) post-treatment, and ultraviolet (UV) light primary disinfection.

The report herein presents the results of the evaluation of all of these additional treatment process alternatives.

### Control Strategies

In general, there are three recognized, major approaches to mitigating disinfection byproducts (DBPs) formed by the use of chlorination:

- Removal of DBP precursors
- Change to an alternative disinfectant
- Removal of DBPs after formation

The Town has already evaluated the removal of DBP precursors associated with implementing Enhanced Coagulation and evaluates herein precursor removal associated with MIEX® anion resin pre-treatment and GAC (granular activated carbon) post-treatment.

The Town also evaluates herein several changes in its use of sodium hypochlorite as both primary and secondary disinfectant. These changes include: (1) the use of sodium hypochlorite for primary disinfection and the use of chloramination for secondary disinfection, and (2) the use of ultraviolet (UV) radiation for primary disinfection and the use of sodium hypochlorite or chloramination for secondary disinfection.

Further, the Town evaluates herein the use of aeration for the removal of DBPs both in the finished water leaving the SWTP and in the distribution system water that have already formed from the use of sodium hypochlorite for both primary and secondary disinfection.

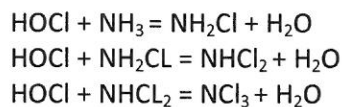
### **Chloramination**

#### ***Process Overview***

Chloramination has been practiced in the United States since 1914 with the City of Denver, Colorado. A 2005 survey by the American Water Works Association found that approximately one-third of all utilities now use chloramines. Municipalities in New Hampshire that provide drinking water treated with chloramines include Manchester, Concord, Salem, and Hillsborough.

Chloramines are formed by the reaction of hypochlorous acid and a source of nitrogen (typically gaseous ammonia, liquid ammonia, solid ammonium sulfate, or liquid ammonium sulfate). Monochloramine is the preferred chloramine species because of its greater disinfecting strength and because of taste and odor problems associated with the other chloramine species: dichloramine and trichloramine (nitrogen trichloride). Industry practice is to use a chlorine to nitrogen weight ratio in the range of 3:1 to 5:1, with a typical value of 4:1. This limits the formation of dichloramine and trichloramine due to an excess of chlorine and limits the potential of nitrification in the distribution system due to excess ammonia. The rate of monochloramine formation is pH sensitive. At a pH of 7.0, the conversion time is approximately 0.2 seconds while at a pH of 8.3 it decreases to approximately 0.07 seconds.

The equations defining the reactions are:



The effectiveness of chloramines to control DBP production depends on a number of factors, most notably the chlorine to nitrogen ratio, pH, and the point of nitrogen addition relative to that of chlorine. The use of chloramines results in the production of DBPs, especially TTHMs, to a much lesser degree than from an equivalent dose of free chlorine. Either chlorine or ammonia may be added first in the formation of chloramines. If chlorine is added first, then DBPs will form until ammonia is added to significantly reduce the rate of the formation reaction. This would be the case at the Exeter SWTP since the stronger disinfecting power of free chlorine is needed first in the clearwell to meet CT requirements of the Surface Water Treatment Rule for *Giardia* cyst and virus inactivation. Typically, a chloramine residual in the range of 2.0 to 3.0 mg/L (as combined chlorine) is desirable to maintain within distribution systems.



Chloramines do decay and release ammonia throughout the distribution system increasing the potential for nitrification episodes. Decay occurs due to auto-decomposition and reaction mechanisms with natural organic matter (NOM) and any nitrite formed by ammonia-oxidizing bacteria.

#### ***Process Implementation and Integration***

Implementation of chloramination at the SWTP would involve continuation of sodium hypochlorite feed to the clearwell to meet CT compliance requirements (primary disinfection) and installation of a new ammonium sulfate feed system that would feed a 35-40 percent solution (by weight) to the discharge piping of the finished water pumps. Here the ammonium sulfate would combine with any free chlorine leaving the clearwell plus additional free chlorine (as sodium hypochlorite) that was required to be fed after the clearwell so that the desired chlorine to nitrogen ratio and monochloramine concentration would be achieved. The ammonium sulfate solution could be purchased in 55-gallon drums, 265-gallon totes, or in bulk and would be fed using chemical metering pumps. Chemical spill containment would also be provided.

Chloramination would also be instituted at the groundwater treatment plant (GWTP) so that there would not be any blending of both chloraminated and chlorinated water within the distribution system. Ammonium sulfate storage and feed equipment would be installed at the GWTP as installed at the SWTP. The ammonium sulfate solution would be fed downstream of the greensand filtration system where it would combine with any free chlorine remaining from the addition of sodium hypochlorite upstream of the filtration system and any additional free chlorine that was required to be fed after the filtration system so that the desired chlorine to nitrogen ratio and monochloramine concentration could be achieved.

It is important to maintain the proper chlorine to ammonia ratio and assure that there is no free ammonia in the distribution system that could lead to nitrification. On-line monitoring of monochloramine; total and free ammonia; and total chlorine leaving the SWTP can be provided by an ASA Analytics Chemscan® 2150/S Chloramination Analyzer. This instrument is installed at the Hillsborough, New Hampshire water treatment plant and is highly recommended by the plant operator. An alternative instrument, the Hach 5500 SC Ammonia Monochloramine analyzer, provides on-line monitoring of total and free ammonia as well as monochloramine.

#### ***Projected Performance***

In mid-November 2016, a filtered water sample from the SWTP was sent to Eastern Analytical Inc. laboratory in Concord, NH so that a side-by-side comparison of Simulated Distribution System (SDS) TTHM and HAA-5 formation for chlorinated and chloraminated filtered water samples could be made.

The filtered water sample had the following chemical characteristics:

- Total Alkalinity: 30 mg/L
- Total Residual Chlorine: <0.05 mg/L
- Free Chlorine: <0.05 mg/L
- Total organic carbon (TOC): 3.4 mg/L
- UVA: 0.0585 1/cm
- pH: 7.0

The SDS protocol for the filtered water sample to be chlorinated included initially adding sodium hypochlorite to achieve a free chlorine concentration of 1.5 mg/L and adding sodium hydroxide to



achieve a pH of 7.5. The sample was incubated at 20 degrees Centigrade throughout the testing. TTHM, pH, free chlorine, and total residual chlorine values were measured thereafter at approximately 1.5, 7.0, 22.5, 47.5, and 72.5 hours. HAA-5 values were measured after the 7.0 and 72.5 hour marks.

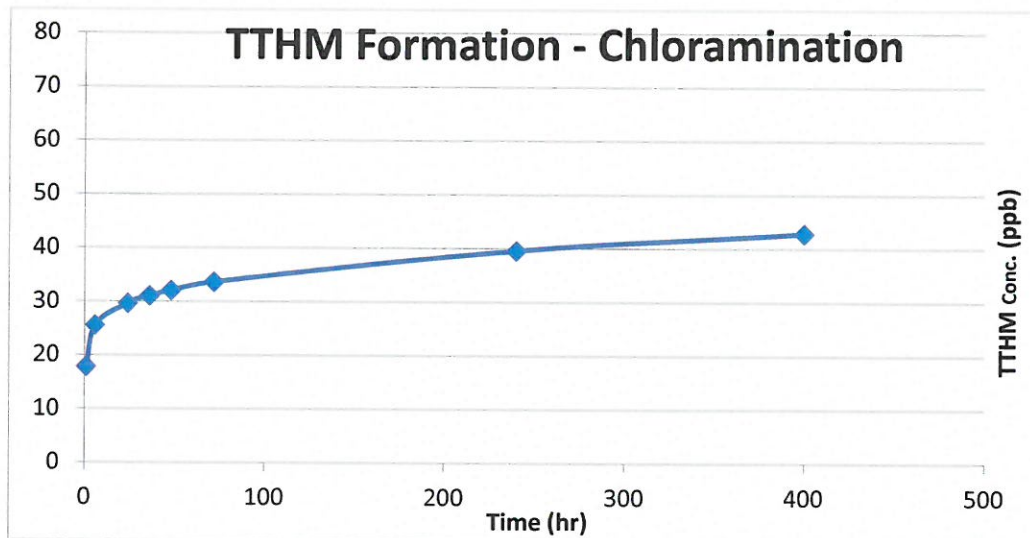
The SDS protocol for the filtered water sample to be chloraminated included initially adding sodium hypochlorite to achieve a free chlorine concentration of 1.5 mg/L. After 1.5 hours (the typical time water is in the clearwell) sodium hydroxide was added to achieve a pH of 7.8, sodium hypochlorite was added to achieve a free chlorine concentration of 3.0 mg/L, and ammonium chloride was added to achieve a nitrogen concentration of 0.75 mg/L. This produced a monochloramine concentration of 3.0 mg/L with a chlorine to nitrogen ratio of 4.0. The sample was incubated at 20 degrees Centigrade throughout the testing. TTHM, pH, free chlorine, and total residual chlorine values were measured thereafter at approximately 2.0, 7.0, 22.5, 47.5, and 72.5 hours. HAA-5 values were measured after the 7.0 and 72.5 hour marks.

The SDS TTHM and HAA-5 values for the chlorinated and chloraminated filtered water samples were as follows:

Time (hr)	Chlorinated Sample		Chloraminated Sample	
	TTHM (ppb)	HAA-5 (ppb)	TTHM (ppb)	HAA-5 (ppb)
0.0	<2.0	-	<2.0	-
1.5	25.1	-	-	-
2.0	-	-	34.0	-
7.0	40.3	23	34.2	19.3
22.5	52.9	-	35.5	-
47.5	54.9	-	34.7	-
72.5	59.3	28	37.3	23.4

The above data shows that the TTHM concentration of the chlorinated water leaving the clearwell after 1.5 hours would be approximately 25 ppb and would continue to increase to approximately 59 ppb after 72.5 hours. If the chlorinated water leaving the clearwell after 1.5 hours was converted to chloraminated water at that point, then the rate of formation of TTHMs slows down considerably as would be expected and only reaches approximately 37.3 ppb after 72.5 hours. This is a reduction of 37-percent compared to the chlorinated water. For time periods in the distribution system (water age) beyond 72.5 hours, the rate of TTHM formation of the chlorinated water would continue to be greater than that for the chloraminated water. Thus the percent difference in respective TTHM concentrations associated with each disinfection practice would increase above 37-percent.

The USEPA computer software, *Water Treatment Plant Model*, projects TTHM formation for chloramines and showed close correlation with the chloramine SDS testing results presented above. This software was specifically developed by the USEPA in support of the Disinfectant/Disinfection Byproduct Rule. The chart below shows TTHM concentrations projected to 400 hours under the same conditions used during the SDS testing except for a higher water temperature of 25 degrees Centigrade.



Findings included in the report, “*Exeter Water Age Study*” prepared by Weston & Sampson in April 2017, showed the following water age and percent contributions from the SWTP and GWTP in the area of the four TTHM compliance sampling points for the Summer Average Day Demand:

TTHM Sampling Point	Water Age (hr)	SWTP (% Water)	GWTP (% Water)
Epping Road Tank Area	155	30 -35	65 - 70
Cross Road Tank Area	390	10-30	70 -90
Hampton Road Tank Area	310	65 - 90	10 - 35
11 Downing Court	35	100	0

The report showed the following for the Winter Average Day Demand:

TTHM Sampling Point	Water Age (hr)	SWTP (% Water)	GWTP (% Water)
Epping Road Tank Area	190	30 -35	65 - 70
Cross Road Tank Area	340	20-30	70 -80
Hampton Road Tank Area	160	90-100	0 - 10
11 Downing Court	35	100	0

Using the this water age data along with the conservative assumption that 100% of the water is from the SWTP (the TTHM concentration of the finished water leaving the GWTP and its increase in the distribution system over time are less than those of the SWTP) , and the TTHM formation projection shown above for chloramination, the estimated TTHM concentrations in the area of each of the four TTHM compliance sampling locations under Summer Average Day conditions (highest THM formation) would be as follows:

TTHM Sampling Point	Water Age (hr)	TTHM Conc. (ppb)
Epping Road Tank Area	155	37
Cross Road Tank Area	390	42
Hampton Road Tank Area	310	40
11 Downing Court	35	30

Thus, it would be expected that the Locational Running Annual Average (LRAA) which includes the TTHM concentrations for four consecutive quarters (seasons) at each of the TTHM compliance sampling points would be in the approximate range of 25 to 35 ppb, well below the maximum contaminant level (MCL) of 80 ppb.

Testing for nitrosodimethylamine (NDMA), a non-regulated disinfectant byproduct of chloramination, conducted in conjunction with the TTHM SDS testing cited above, showed a concentration of less than 1 ppb.

### ***Process Advantages and Disadvantages***

Chloramination is an established technology that has been successfully used at a number of water treatment plants nationwide including four in the State of New Hampshire. Chloramines are more stable and longer lasting than chlorine or sodium hypochlorite and thus provide better protection against bacterial regrowth within distribution systems.

Several of the concerns associated with using chloramines as a disinfectant include: corrosion of lead and copper in pipes, nitrification within the distribution system, impact on dialysis equipment, odor and taste development, impact on fish and amphibians within fishbowls and aquariums, potential complaints of skin and respiratory problems, long-term and acute health effects of chloramine specific disinfection byproducts such as nitrosamines. Fortunately, municipalities that have converted from chlorination to chloramination have found remedies to these problems which Exeter could implementing if needed.

### ***Costs***

The estimated construction cost for a chloramine feed system including a Chemsan® 2150/S Chloramination Analyzer for the SWTP is \$85,000 and that for the GWTP is also \$85,000 for a total construction cost of \$170,000.

Engineering and contingencies are estimated to be \$85,000 based on 50% of the total construction cost.

The estimated annual chemical cost based on using 40-percent liquid ammonium sulfate solution in 55-gallon drums, 4:1 chlorine to nitrogen weight ratio, 3 mg/L monochloramine dosage, and 1 million gallons per day (mgd) annual average flow rate for the SWTP and 1 mgd annual average flow rate for the GWTP is \$24,000 per year.

### **Aeration**

Trihalomethanes (THMs), one group of disinfection byproducts (DBPs), are relatively volatile organic compound gasses that are dissolved in water, and thus can be transferred from the water phase to the air phase by the aeration process as governed by Henry's Law. Of the four THM species regulated by the Stage 2 D/DBP Rule, chloroform is the easiest to remove by aeration followed by bromodichloromethane, dibromochloromethane, and bromoform. It has been shown that aeration does not significantly reduce existing chlorine residual levels. Haloacetic acids (HAAs), another group of regulated DBPs, are not effectively removed by aeration as they are significantly less volatile than THMs.

There are three major aeration technologies that can be used for THM reduction:



- Floating surface spray aeration
- Fixed nozzle spray aeration
- Diffused bubble aeration

Floating surface spray aeration systems include mixers that assist in transferring water from the bottom of a tank or basin to the surface where it is sprayed through nozzles on the floating aerator to allow gas transfer to occur. The technology's capability to reduce THMs depends on design considerations such as air to water ratio, water detention time, water droplet diameter, headspace above the water surface, and proper ventilation, typically requiring fans and enhanced ventilation.

Fixed nozzle spray aeration systems draw water from the bottom of a tank or basin using a pump and then spray it through nozzles located on an array of fixed piping into the headspace above the water surface. Similar to floating surface spray aeration, the effectiveness of THM reduction depends upon factors such as water droplet diameter, travel time in air before landing on the surface of the water, and proper ventilation.

Diffused bubble aeration systems diffuses tiny bubbles into the tank or basin which travel up through the water column, creating air to water contact for gas transfer to take place. Factors affecting THM reduction include air bubble diameter, air to water ratio, water depth above the air diffuser, detention time, proper ventilation, and water temperature.

The two spray aeration technologies are the most commonly used and can achieve 20-70 percent reduction in THMs. Typical aeration applications include installation within plant clearwells to reduce early forming THMs and/or installation within distribution storage tanks to reduce THMs from the water stored in these tanks at strategic locations in the distribution system. Although less common, another potential application is the installation of an aeration system within the distribution system downstream of the clearwell and upstream of storage tanks. This application reduces THMs from distribution system water trapped in dead-end locations.

The installation of mixers and special vents alone within distribution storage tanks, although not as effective as the aeration technologies described above, can reportedly achieve 10-15 percent reduction in THMs.

### ***Process Implementation and Integration***

Based on analysis of the formation and concentrations of THMs at the SWTP and within the distribution system, installation of spray aeration at the SWTP would be the best application to achieve DBP compliance. However, to achieve the most effective THM removal, the aeration system would not be installed within the SWTP clearwell as is typically done due to limited headspace considerations. Rather, finished water with its early formed THMs would first be low-lift pumped from the SWTP clearwell to the existing, below-grade concrete Recycle Basin which would become dedicated for this purpose. It is in this basin that the aeration system would be installed. Aerated water from this basin would be high-lift pumped into the distribution system.

The existing Recycle Basin consists of two parallel channels each approximately 16 feet by 31 feet in plan and 12.5 feet deep. In order to achieve a guaranteed 40% THM removal by the aeration system, the height of each channel would be increased to approximately 20 feet and capped. This would allow the

water level in each channel to be 15 feet deep with a 5-foot headspace above the water level. Each channel would be equipped with three (3) 7.5 hp surface aerators, special vents, and one (1) mixing system. A control panel would monitor the system operation.

Enhanced ventilation and mixers would also be installed in all three distribution system storage tanks (Cross Road, Epping Road, and Hampton Road) to enhance THM removal at these locations which comprise three of the four distribution system sampling locations for DBP compliance.

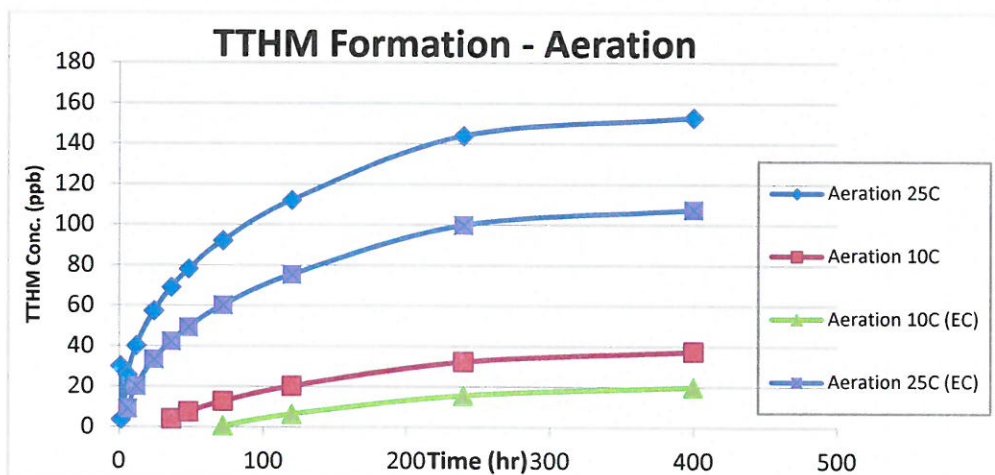
### ***Projected Performance***

Suez, a supplier of PAX Water Technologies spray aeration equipment, has proposed to guarantee 40-percent removal of THMs from the chlorinated finished water entering the Recycle Basin using the aeration system described above at a design flow rate of 1.5 mgd. While the percent reduction at the Recycle Basin would be guaranteed at 40-percent, it would be less as a function of travel time from the SWTP for locations in the distribution system since the THM concentrations at these locations would be greater than at the Recycle Basin.

The reduction in THM concentration (ppb) at the Recycle Basin would depend upon the concentration of early formed THMs entering the Recycle Basin. This would be variable and depend upon the season of the year (raw water temperature), applied sodium hypochlorite dosage to the clearwell, SWTP flow rate and filtered water TOC concentration entering the clearwell. The reduction in THM concentration at the Recycle Basin would then be the numerical concentration reduction realized at every location in the distribution system.

In addition, Suez has estimated that installation of its Powervent™ system in each of the distribution system storage tanks together with existing mixers in each tank would achieve an additional 10-15 percent THM removal at these locations.

Based on the calibrated TTHM formation model developed by Amy et al., 40-percent TTHM reduction in the Recycle Basin, 10-percent TTHM reduction from Powervent™ installation in the Cross Road Tank, and TTHM concentrations of 50 ppb and 40 ppb during the summer (25 C) and spring/fall (10 C) seasons, respectively entering the Recycle Basin, the projected TTHM formation for aeration would be as shown below for SWTP routine and enhanced coagulation conditions.



Using the previously cited water age data, the conservative assumption that 100% of the water is from the SWTP and the TTHM formation projection shown above for 25C SWTP and enhanced coagulation (EC) aeration, the estimated TTHM concentration range at each of the four TTHM compliance sampling locations under summer average day conditions would be as follows:

<b>TTHM Sampling Point</b>	<b>Water Age (hr)</b>	<b>TTHM Conc. (ppb)</b>
Epping Road Tank Area	155	90-130
Cross Road Tank Area	390	110-155
Hampton Road Tank Area	310	105-150
11 Downing Court	35	40-70

It is estimated that the Locational Running Annual Average (LRAA) which includes the TTHM concentrations for four consecutive quarters (seasons) at each of the TTHM sampling points would be in the approximate range of 25 to 65 ppb for SWTP coagulation chemistry and 25 to 45 ppb for enhanced coagulation, both below the MCL of 80 ppb.

#### ***Process Advantages and Disadvantages***

The use of aeration to reduce THMs from water after their formation is a well established technology that has been used successfully at a number of water treatment plants. As a result, it is possible for system suppliers to guarantee THM removal percentages for a new installation based on specific aeration tank dimensions, turnover rates, water quality conditions, and treatment goals. However, the TTHM concentration reduction cannot be guaranteed since it depends upon the TTHM concentration that has formed prior to aeration. There are no analogous aeration systems currently installed at New Hampshire water treatment plants. The two major suppliers of spray aeration systems used in clearwells and storage tanks are PAX Water Technologies and Medora Corporation.

Aeration is a mechanical process that does not introduce new treatment chemicals to the water and is relatively simple to operate and monitor. However, aeration can affect critical water quality parameters including pH and dissolved oxygen concentrations which can potentially influence corrosion control stability.

Installation of aeration equipment in the Recycle Basin would require considerable finished water pumping and piping reconfiguration as well as structural modifications to the basin. The structural modifications would cause a sizable reduction in the yard area available for chemical truck deliveries.

#### ***Costs***

Suez estimates the cost of construction and installation as follows: the construction cost for the aeration equipment located within the Recycle Basin is \$549,000; the construction cost for modifications to pump finished water from the SWTP clearwell to the Recycle Basin and from the Recycle Basin to the distribution system is \$755,000; and the cost to install Powervent™ systems in the Hampton Road and the Cross Road storage tanks is \$65,000. (The Powervent™ system for the Epping Road tank has already been purchased by Exeter.) The construction cost associated with Recycle Basin modifications to extend the height of the channel walls and cap them is estimated to be \$100,000. The total construction cost is thus estimated to be \$1,469,000.



Engineering and contingencies includes the Suez estimate for engineering the pumping and piping modifications at \$90,000 plus 50% of the construction cost associated with the aeration equipment in the Recycle Basin and storage tanks plus the Recycle Basin modifications for a total of \$447,000 ( $\$90,000 + 0.5 (\$549,000 + \$65,000 + \$100,000)$ ).

The estimated annual cost for electrical power is \$16,000 per year based on 12 hour per day, 365 day per year operation of the aeration system and the cost of electricity at \$0.10/KwH. Suez estimates that the cost of its Maintenance Program Services is approximately \$45,200 per year. This program includes:

- Warranty on the system for the life of the agreement
- Annual inspection of the operation of the system
- Labor and materials to maintain the system to its original performance
- Remote monitoring of the system
- Responding to any performance issues

### **MIEX® Anion Resin**

MIEX® Anion Resin specifically targets the removal of dissolved ionic organic carbon (DOC) precursor compounds such as humic and fulvic acids from water supplies. These negatively charged ions (anions) are removed from water by exchanging with a chloride ion on active sites at the resin surface. The chloride concentration of the treated water typically increases by 15 to 20 mg/L. The very small size of the magnetized resin allows the removal of anions to occur in a stirred contactor. Under these mixing conditions, the resin beads are uniformly dispersed to maximize the kinetics of ion exchange and minimize the resin media inventory. The magnetic component built into the resin bead allows them to rapidly agglomerate into rapid settling particles when mixing is stopped. This in turn permits settlers to be used for resin-water separation, with treated water overflowing from the settler and settled resin being recovered as a concentrated underflow stream, most of which is reintroduced to the mixing contactor. A small percentage of the underflow is sent to a resin regeneration tank and an equivalent amount of regenerated resin is added back to maintain the concentration of resin in the mixing contactor. Once there is a sufficient volume of resin in the regeneration tank, the resin is regenerated using a 12-percent brine (sodium chloride) solution and eventually transferred to a feed tank for reintroduction into the treatment process. Periodically a portion of the brine containing concentrated organic matter is wasted from the regeneration tank. Sodium bicarbonate can be used as the regenerant in place of salt (sodium chloride).

The MIEX® process may be used as pre-treatment upstream of coagulation as it is not affected by suspended solids (turbidity) or downstream of coagulation as a polishing step. The process supplier, IXOM Watercare recommends that it be used as pretreatment to remove DOC at the head of the plant since it can provide benefits to the downstream processes such as less coagulant use and thus less chemical sludge production. The usage of any oxidant fed downstream of the MIEX® process would also likely be reduced due to a decrease in the oxidant demand associated with DOC.

### ***Process Implementation and Integration***

The MIEX® process would become the first treatment stage at the Exeter SWTP and would treat raw water from either the Pond or the Exeter River. The existing raw water pipe configuration just outside

the SWTP would need to be modified to allow either source to feed the treatment process and to return the processed water to the current headworks of the SWTP.

The major treatment process equipment would include two (2) 11-ft diameter resin contactor/settlers, two (2) resin regeneration skids, 20-ton salt saturator, and brine feed tank. This equipment would be housed in a new building approximately 35 ft by 60 ft by 20 ft high. A waste connection for the spent brine regenerant would also be required.

### ***Projected Performance***

In mid-January 2017, raw water samples from the Pond were sent to the Ixom Watercare laboratory in Centennial, Colorado for the purpose of conducting bench scale testing of the MIEX process alone and in combination with coagulation. The sample had the following chemical characteristics:

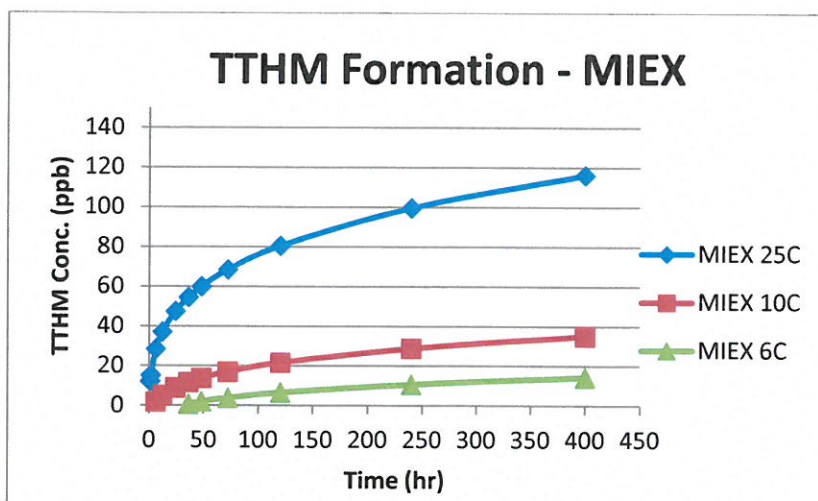
- Total Alkalinity: 31 mg/L
- Dissolved Organic Carbon (DOC): 8.99 mg/L
- UVA: 0.302 1/cm
- SUVA (Specific Ultraviolet Adsorption): 3.36 L/mg-m
- pH: 6.9
- Chloride: 103 mg/L
- Iron: 0.48 mg/L
- Manganese: 0.326 mg/L

Testing showed that the MIEX® “DOC” resin treatment alone could reduce DOC from 8.99 to 3.40 mg/L (62-percent removal) and UVA from 0.302 to 0.077 1/cm (75-percent removal) at a Bed Volume (BV) of 200 (volumetric ratio of treated water to resin). However, at the IXOM Watercare recommended BV of 600 selected for cost-effectiveness, the DOC and UVA removals were somewhat less at 59-percent and 68-percent, respectively.

Testing the raw water sample for DOC and UVA removal using the coagulant currently used at the SWTP (PC-605 polyaluminum chloride) at a dose of 40 mg/L showed a DOC reduction of 39.7-percent and UVA reduction of 73.8-percent. Increasing the dose up to 65 mg/L resulted in a DOC reduction of 43.3-percent and a UVA reduction of 80.8-percent.

When the combination of MIEX® “DOC” resin at a BV of 600 followed by coagulation with 30 mg/L of PC 605 was tested, the DOC removal increased to 62.8-percent (DOC of 3.34 mg/L) while the UVA removal increased to 91.7-percent (UVA of 0.025 1/cm). This demonstrated the treatment performance benefit of using the MIEX® process as pretreatment upstream of the current coagulation used at the SWTP and the reduction in coagulant dose that could potentially be realized.

Based on using a calibrated TTHM formation model developed by Amy et al., the projected TTHM formation for MIEX® “DOC” resin would be as shown below:



Using the previously cited water age data, the conservative assumption that 100% of the water is from the SWTP, and the TTHM formation projection shown above for the MIEX® process, the estimated TTHM concentrations at each of the four TTHM compliance sampling locations under summer average day conditions would be as follows:

TTHM Sampling Point	Water Age (hr)	TTHM Conc. (ppb)
Epping Road Tank Area	155	90
Cross Road Tank Area	390	118
Hampton Road Tank Area	310	112
11 Downing Court	35	55

It is estimated that the Locational Running Annual Average (LRAA) which includes the TTHM concentrations for four consecutive quarters at each of the TTHM compliance sampling points would be in the approximate range of 30 to 55 ppb; concentrations that are below the maximum contaminant level (MCL) of 80 ppb

#### ***Process Advantages and Disadvantages***

This resin has the capability to remove the low molecular weight fraction of DOC that cannot be removed by coagulation. This results in lower treated water DOC and UVA levels and consequently lower THMs. Used as pretreatment to conventional coagulation results in lower coagulant doses being required to achieve targeted water quality goals and less chemical sludge being produced. The process could be used only seasonally and/or partially bypassed as needed to achieve desired DOC reductions.

Although the use of anion resin to remove organic constituents has been used for many years, the MIEX® process as described is proprietary. There are no municipalities in New Hampshire that use this process and so NHDES new technology review and approval would be required.

A new 2,100 square foot building along with modifications to the existing raw water piping configuration just outside of the SWTP would be needed to accommodate the process. In addition, the typical use of



salt (sodium chloride) as a resin regenerant would increase the chloride concentration of the treated water by approximately 15 to 20 mg/L and require periodic disposal of a concentrated brine regenerant stream.

### **Costs**

The estimated construction cost for a 2-mgd MIEX® system is \$1,913,000 for the treatment, \$150,000 for raw water piping modifications, and \$300,000 for the building for a total construction cost of \$2,363,000.

Engineering and contingencies are estimated to be \$1,182,000 based on 50% of the total construction cost.

The estimated annual cost of resin, electric power, and salt based on 1-mgd annual average flow rate for the SWTP is approximately \$34,000 per year.

### **Granular Activated Carbon (GAC)**

Adsorption onto granular activated carbon (GAC) can remove DBP precursors from water supplies. Important properties of GAC that determine its effectiveness include: GAC particle size, specific surface area, pore size distribution, and chemical nature of the surface. GAC adsorption is a non-steady state process whereby the effluent concentration of the contaminant increases over time. Once the effluent concentration reaches the maximum concentration desired, the GAC media must be taken out of service and replaced with either reactivated or virgin GAC. Operation in this mode would result in only a portion of the GAC being fully utilized. Operating multiple GAC contactors in series configuration (lead-lag) is a method to reduce GAC usage rates. The GAC in the first contactor is reactivated or replaced when the effluent concentration from the lag contactor no longer meets the treatment objective. Once this occurs, the position of the two contactors is reversed, with what was originally the second contactor (lag contactor) becoming the first contactor (lead contactor) and visa versa.

The Empty Bed Contact Time (EBCT) is defined as the volume of media divided by the flow rate. GAC contactors, containing only GAC media beds, are used when relative long EBCTs are required, such as for the removal of DBP precursors. Downflow fixed-bed contactors (either pressure or gravity) are the most common configuration used for drinking water treatment. These contactors are typically placed downstream of plant filters to minimize the solids loading on the contactor.

In general the GAC process favors removal of natural organic matter (NOM) molecules of low to moderate size. This phenomenon occurs because small GAC pores physically exclude large NOM molecules from adsorbing. As a result, GAC media with a greater number of large pores can be expected to remove more NOM than GAC media with a small quantity of large pores. Coagulation, as a pretreatment to GAC adsorption, can reduce build-up of solids on the GAC bed, reduce influent TOC loading and decrease the influent pH leading to improved GAC performance.

### ***Process Implementation and Integration***

GAC contactors would become the last treatment stage at the SWTP and would treat filtered water prior to the clearwell. The existing filtered water piping from all four filters would need to be modified to

allow filtered water to be pumped through the GAC contactors and returned to the SWTP clearwell for disinfection.

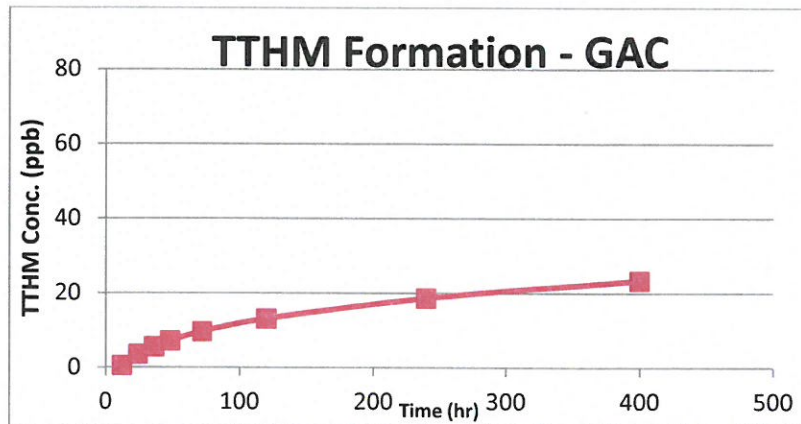
The major treatment process equipment would include two GAC pre-assembled skids each containing two (2) 10-ft diameter GAC contactors (four contactor vessels total) that would operate in parallel. Each contactor vessel contains 20,000 pounds of granular activated carbon. The pre-assembled skids include piping, manual valves, and instrumentation. A supply of media backwash water at 1,200 gpm and utility air (100 scfm at 30 psig) for exhausted GAC discharge and fresh GAC fill operations would be needed. The normal pressure drop across each skid is 10-12 pounds per square inch (psi). This equipment would be housed in a new building approximately 40 ft by 45 ft by 25 ft high.

### ***Projected Performance***

It is estimated by Calgon Carbon Corporation (Calgon), a major supplier of GAC systems and various types of granular activated carbon, that with lead-lag operation of each GAC skid, the TOC concentration in the effluent from the lag contactor would initially be approximately 0.1 mg/L and then increase to approximately 0.5 mg/L at the point of the lead contactor becoming exhausted. Calgon further estimates that the 20,000 pounds of GAC in the lead contactor of a skid would become exhausted and need to be replaced every 60 days based on the skid treating 1 mgd and an influent TOC concentration of 3 mg/L in the filtered water.

These GAC usage and performance estimates are based on Calgon proprietary predictive models. More accurate estimates would require that carbon isotherm testing be conducted on filtered water from the Exeter SWTP.

Based on the calibrated TTHM formation model developed by Amy et al. and a water temperature of 25 degrees Centigrade, the projected TTHM formation for the GAC process would be as shown below:



Using the previously cited water age data, the conservative assumption that 100% of the water is from the SWTP, and the TTHM formation projection shown above for the GAC process, the estimated TTHM concentrations at each of the four TTHM sampling locations under summer average day conditions would be as follows:

<b>TTHM Sampling Point</b>	<b>Water Age (hr)</b>	<b>TTHM Conc. (ppb)</b>
Epping Road Tank Area	155	17
Cross Road Tank Area	390	22
Hampton Road Tank Area	310	20
11 Downing Court	35	7

Thus, it would be expected that the Locational Running Annual Average (LRAA) which includes the TTHM concentrations for four consecutive quarters at each of the TTHM compliance sampling points would be well below the maximum contaminant level (MCL) of 80 ppb in the approximate range of 20 to 25 ppb.

### ***Process Advantages and Disadvantages***

GAC has the potential to remove TOC in the filtered water to concentrations below 1.0 mg/L and thus result in significant reductions in distribution system THMs. GAC adsorption could be used only seasonally and/or partially bypassed as needed to achieve desired TOC reductions. The process is simple to operate and would not introduce any new treatment chemicals into the drinking water.

TOC removal by the use of GAC has been used for many years and is well established. It is not a proprietary treatment process with multiple suppliers of GAC contactor vessels and types of granular activated carbon. NHDES would be familiar with this treatment process.

A new 1,800 square foot building along with modifications to the existing filtered water piping configuration inside of the SWTP would be needed to accommodate the process.

### ***Costs***

The estimated construction costs are: \$750,000 for a 2-mgd GAC system associated with the treatment, \$400,000 for filtered water piping modifications, and \$270,000 for the building for a total construction cost of \$1,420,000.

Engineering and contingencies are estimated at \$710,000 based on 50% of the total construction cost.

The estimated annual cost of GAC replacement based on 1-mgd annual average flow rate for the SWTP is approximately \$120,000 per year and electricity for pumping through the system is \$3,500 per year.

### **Ultraviolet (UV) Light**

The use of ultraviolet (UV) light for disinfection is accomplished by irradiating water with UV light, which alters the structure of the deoxyribonucleic acid (DNA) of the microorganisms in the treated water and thereby prevents the proper replication of the DNA strands. UV does not directly form DBPs and has been shown not to alter the concentration or species of DBPs formed by post-disinfection with chlorine or chloramines. UV light is electromagnetic radiation having wavelengths between 100 and 400 nanometers (nm). The effective germicidal wavelength range for most microorganisms is generally considered to be between 200 and 300 nm. Since UV disinfection is a physical rather than a chemical disinfectant, it does not provide a residual and therefore requires the use of a secondary disinfectant to maintain water quality in the distribution system.



UV systems consist of UV reactors and an associated control panel. UV reactors for drinking water applications are closed reactors containing UV lamps, quartz sleeves, UV intensity sensors, quartz sleeve wipers, and temperature sensors. UV intensity sensors, flow meters, and UV transmittance monitors are used to monitor dose delivery by the reactor. The UV lamp ballast controls the amount of electricity supplied to the lamp and ensures a consistent and constant power delivery. Continuous wave UV lamps most commonly used include low pressure mercury vapor (LP), low pressure high output (LPHO), and medium pressure mercury vapor (MP), with “pressure” referring to the pressure of mercury vapor within the lamp. The light emitted by the LP and LPHO lamps are essentially monochromatic at 253.7 nm, which is in the range of the most germicidal wavelengths for microorganisms. MP lamps emit at a higher intensity than LP lamps but at a wide range of wavelengths (200-300 nm).

The UV dose is the product of the intensity of the UV energy and the exposure time. The UV dose necessary for inactivation of microorganisms varies from species to species, with increasing UV dose resulting in increased microorganism inactivation. Viruses are the most resistant to UV disinfection followed by bacteria and protozoa. UV used as primary disinfection at Exeter would be required to achieve 2-log inactivation of viruses and 0.5-log inactivation of *Giardia* cysts. The UV dose is expressed in units of milli-Joules per square centimeter ( $\text{mJ}/\text{cm}^2$ ) and the dose requirements for various log inactivation can be found in the USEPA UV Disinfection Guidance Manual, Appendix B. The effectiveness of UV light is not impacted by pH and temperature, as is the case with some disinfectants. However, any conditions that interfere with the UV energy being transmitted through water adversely impacts disinfection efficiency. These conditions may include: turbidity, chemical and biological films that coat the surface of the UV lamps, color, and dissolved organics. A reliable high-quality electric power supply is recommended for UV systems.

The major UV system suppliers for drinking water applications include Atlantium, Calgon Carbon Corporation - Sentinel, and Aquionics. Atlantium supplied the UV system currently installed at the Hillsborough, New Hampshire water treatment plant.

### ***Process Implementation and Integration***

The typical installation location of UV reactors in the outlet piping of the filtration system. However this is not possible at the Exeter SWTP because of the significant piping reconfiguration it would require. Instead, the UV reactors would be installed in a reconfigured finished water pump discharge piping arrangement either within the existing SWTP filter building or within a new structure. The estimated maximum size of the new structure would be approximately 50 feet by 15 feet and 8 feet high. The UV electronic ballast controls would be located in proximity to the UV reactors. The UV system controller would be located in the SWTP control room/laboratory.

UV would provide primary disinfection to meet CT requirements for viruses and *Giardia* cysts. Chlorination and chloramination as secondary disinfectants have been installed both upstream and downstream of UV. In cases where the UV dosage is significantly higher than typically used at drinking water plants, it is recommended that the secondary disinfectants be located downstream because they can be diminished in concentration after passage through the UV system.

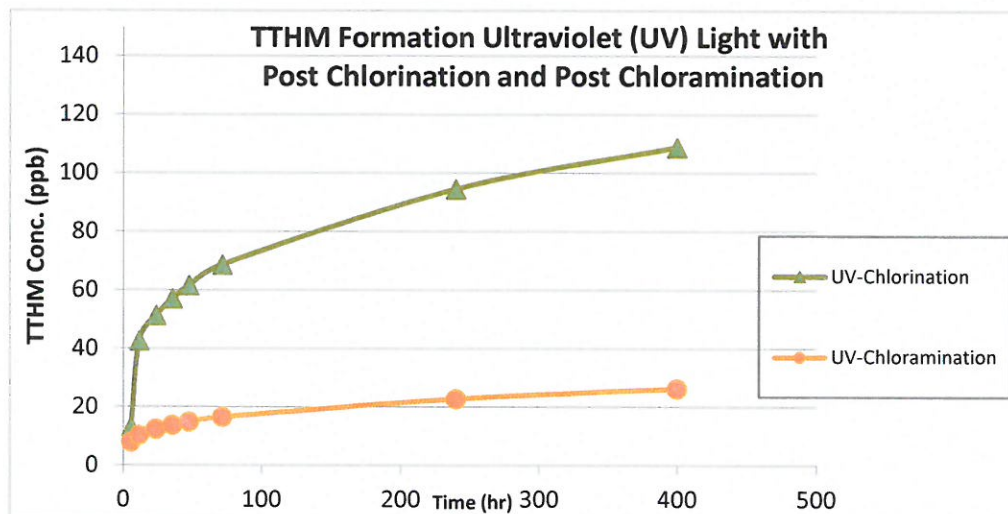
### ***Projected Performance***

UV light does not reduce DBP precursors such as TOC; rather it eliminates the need for a chemical disinfectant to meet CT disinfection requirements (primary disinfection) and its associated production of

DBPs. A secondary disinfectant such as sodium hypochlorite or monochloramine is still needed to maintain residual disinfection in the distribution system. For the Exeter SWTP, the continued use of sodium hypochlorite as a secondary disinfectant would result in a delay in the start of formation of THMs that currently occurs when using sodium hypochlorite in the clearwell for both primary and secondary disinfection. The time length of the delay would vary depending upon the travel time of the water through the clearwell at any given moment. For the most part, this would be approximately one hour when the plant is in service. The net result is that a location in the distribution system where the water age is less by this length of the time would have a reduced THM concentration. Thus, locations close to the SWTP, where the water age may be only several hours, would realize the greatest reduction in THM concentration since the THM formation rate is the greatest early on. Locations where the water age is greater than approximately one day would realize less of a reduction in THMs since the THM formation rate decreases considerably at these locations. Since the estimated water age in the vicinity of the three distribution water storage tanks is greater than 5 days, as presented previously in this report, the use of UV for primary disinfection would not result in a significant THM reduction at any of these compliance sampling points if chlorination is used as the secondary disinfectant.

On the other hand, the use of monochloramine as the secondary disinfectant would result in significant overall THM reduction that would be greater than that achieved by using sodium hypochlorite as the primary disinfectant and monochloramine as the secondary disinfectant.

The USEPA computer software, *Water Treatment Plant Model*, projects TTHM formation for chloramines. The following chart shows TTHM concentrations projected to 400 hours for UV with post-chlorination and UV with post-chloramination at 25 degrees Centigrade.



Using the water age data previously presented, the conservative assumption that 100% of the water is from the SWTP, and the TTHM formation projections shown above, the estimated TTHM concentrations at each of the four TTHM compliance sampling locations under summer average day conditions would be as follows:

TTHM Sampling Point	Water Age (hr)	TTHM Conc. (ppb)	
		UV-Chlorination	UV-Chloramination
Epping Road Tank Area	155	80	20
Cross Road Tank Area	390	110	26
Hampton Road Tank Area	310	100	24
11 Downing Court	35	57	14

The above table shows the significant reduction in the distribution system TTHM concentrations that could possibly be realized when using UV with post-chloramination versus UV with post chlorination. It is estimated that the Locational Running Annual Average (LRAA) which includes the TTHM concentrations for four consecutive quarters at each of the TTHM compliance sampling points for UV with post-chloramination would be well below the maximum contaminant level (MCL) of 80 ppb in the approximate range of 20 to 25 ppb.

#### ***Process Advantages and Disadvantages***

UV is an established means of inactivation of many waterborne pathogens without forming DBPs or adding chemicals to the water. It has also been shown that post-UV disinfection with (chloramination or chlorination) does not impact DBP levels formed by chemical disinfection. There are multiple suppliers of UV equipment. Atlantium, one of these suppliers, provided the UV system that was installed as primary disinfection at the Hillsborough, New Hampshire water treatment plant.

Since UV light does not leave any residual disinfection, secondary disinfection by chlorination or chloramination is required for disinfection of the water distribution system.

The UV reactors at the Exeter SWTP would need to be installed in a reconfigured finished water pump discharge piping arrangement to accommodate either the upstream and downstream straight pipe hydraulic requirements of the selected UV reactor validation or a new validated configuration that would reduce or eliminate the upstream/downstream straight pipe requirements. This location could possibly be within the existing SWTP filter building or within a new structure located on-site.

#### ***Costs***

The estimated construction costs are: \$310,000 for a UV system consisting of two UV trains each with three medium pressure UV lamps that could treat 2 mgd having a UVT (ultraviolet transmittance) of 91.7 percent and provide 2-log virus inactivation and greater than 3-log *Giardia* and *Cryptosporidium* inactivation and \$125,000 for the associated finished water piping modifications, manual and automatic isolation valves, and flow meters for each UV train within the existing SWTP filter building for a total construction cost of \$435,000.

If a new structure is required, its estimated cost would be \$112,500 and the total construction cost would increase to \$547,500.

Engineering and contingencies are estimated at \$217,500 based on 50% of the total construction cost for installation within the existing SWTP filter building. They would increase to \$273,750 should a new structure be required.

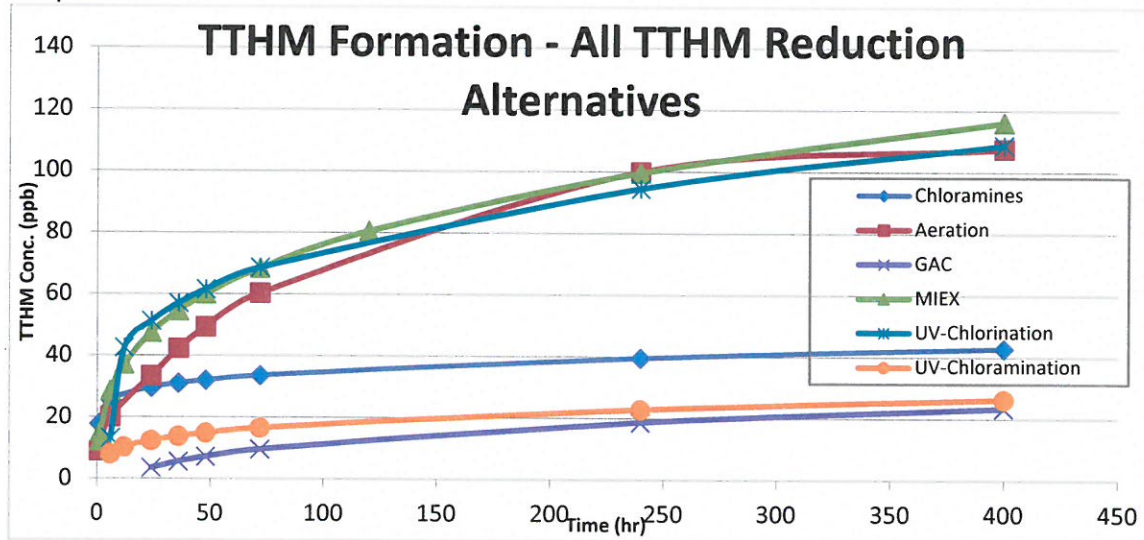


Based on 1-mgd annual average flow rate for the SWTP, the estimated annual cost for electricity is \$11,000 per year. The annual cost for consumables including UV lamps, UV sensors, and ballasts is estimated to be \$7,500 per year.

### Conclusions and Recommendations

Table 1 provides a summary comparison of the TTHM reduction alternatives that were evaluated in the report herein.

The chart below shows the TTHM Formation of all the reduction alternatives evaluated at 25 C water temperature.



Based on the findings of the evaluation, the following conclusions are made:

- The two TTHM reduction alternatives that use monochloramine as the secondary disinfectant (Chloramination and Ultraviolet (UV) with Chloramination) would produce TTHM locational running annual averages (LRAAs) that are well below the MCL of 80 ppb. The model projected LRAA range for the Chloramine alternative is 25 ppb to 35 ppb. The projected LRAA range for the UV with Chloramine alternative is 20 ppb to 25 ppb.
- Chloramination has the lowest total capital cost (construction, engineering plus contingencies) estimated to be \$255,000 and the lowest annual operational and maintenance (O&M) cost estimated to be \$24,000 of all the alternatives.
- UV with Chloramination has the second lowest total capital cost of all the alternatives estimated to be \$652,500 for the UV portion and \$255,000 for the chloramination portion (\$907,500 total) if the UV process can be installed within the existing SWTP filter building. The total capital cost for the UV portion would increase to \$821,500 with the same chloramination capital cost of \$255,000 (\$1,076,500 total) if the UV process required a new structure, which would be the third lowest total capital cost of all the alternatives. The annual O&M cost of



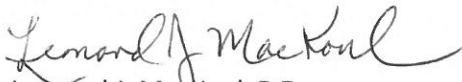
either option is estimated to be \$18,500 for the UV portion and \$24,000 for the chloramination portion (\$42,500 total). This is the third lowest annual O&M cost of all the alternatives.

- The use of chloramination requires careful monitoring of monochloramine formation at the SWTP and GWTP and free ammonia concentrations in the distribution system to avoid potential nitrification conditions. In addition, it requires addressing other water quality issues identified herein resulting from the conversion of chlorination to chloramination as well as providing public notification.
- There would be less TTHM production associated with the UV with Chloramination alternative than the Chloramination alternative during a SWTP process upset that causes increased TOC levels in the finished water. This is due to the fact that there is virtually no period of time during which sodium hypochlorite alone is in contact with the finished water before monochloramine is formed as there is when chlorination is used as the primary disinfectant and is in contact with filtered water for at least one hour.
- The installation of Powervent™ systems within all of the water distribution system storage tanks will decrease TTHM levels by approximately 10-15 percent at these locations. The total capital cost is estimated to be \$65,000.

UV with Chloramination is recommended as the best alternative to reduce TTHMs for Exeter based on its projected performance, capital cost and annual O&M cost. While chloramination requires watchful monitoring and has several water quality concerns, the conditions for its successful use experienced by many municipalities for many years are well documented. The installation location of the UV reactors in the finished water pump discharge piping has not yet been finalized. It may be within the existing SWTP filter building or within a new on-site structure. The final location will require further engineering evaluation and approval by the NHDES regarding its compliance to UV validation conditions.

Exeter intends to install Powervent™ systems in each of its water storage tanks to further enhance TTHM removal.

Very truly yours,  
AQUAGENICS INCORPORATED



Leonard J. MacKoul, P.E.  
Principal